Proceedings of the 17th International Symposium on Power Semiconductor Devices & IC's
May 23-26, 2005 Santa Barbara, CA

A New 80V 32x32ch Low Loss Multiplexer LSI for a 3D Ultrasound Imaging System

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Abstract

This paper presents a new concept for an 80V multiplexer LSI with the world's largest 32 X 32ch cross-point switches for a real-time three-dimensional ultrasound imaging system. This system requires hundreds of thousands of high voltage electrical switches. We propose a new gate floating type analog switch circuit with thin gate oxide power MOSFETs and a low-loss gate driving method for this LSI. The developed LSI can handle ±40V at 15MHz ultrasound signal with reasonably low power dissipation (10mW/LSI) and can operate at a 33MHz clock frequency for the first scanning operation. The developed LSIs are assembled in a hand probe and show a fine 3D volume image.

Introduction

In clinical applications, a 3D ultrasound imaging system has been generalized. For such applications, a 1D-array probe that is mechanically moved has been applied. However, the image quality is poor because of fixed and weak focusing. To form a good isotropic beam in the 3D space, and to obtain good sensitivity, the real-time 3D imaging system using a fully electrically controlled 2D array probe shown in Figure 1 is proposed[1,2]. This 2D array probe, however, requires approximately eight thousand piezoelectric ultrasound transducers with more than 30 system channels to obtain a good clinical image. Therefore hundreds of thousands of high voltage electrical switches in the multiplexer configuration are required to control the ultrasound beam, and these switches must be very small and very low loss so that they can be assembled in the small hand probe. Moreover, a high-speed logic processor is also required for the fast scanning operation.

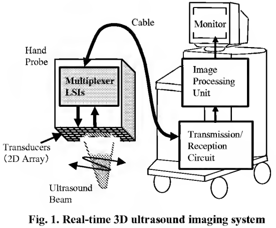


Fig. 1. Real-time 3D ultrasound imaging system using 2D array probe

Conventional multiplexer ICs have been developed mainly for audio and video systems[3]. The blocking voltages of these ICs are a few tens of volts. The ultrasound imaging system requires high voltage analog switches to receive high voltage signals (>50V) [4,5]. Furthermore, for the 3D ultrasound imaging system, the number of switches is needed about 100 times more to be assembled in a small probe.

In this paper, we present a new concept for a multiplexer LSI with the world's largest 80V 32 X 32ch cross-point switches to satisfy the above requirements. We have developed a new gate floating type analog switch circuit with thin gate oxide power MOSFETs for small chip size, and a very low-loss gate driving method is proposed. Moreover, we have also adopted a new switching noise reduction method, and optimized device structures for a wider analog signal bandwidth by low parasitic capacitance.

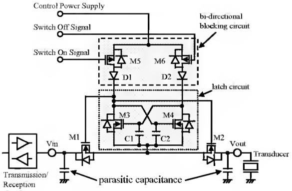
New Gate Floating Type Analog Switch Circuit

A. Concept of the new analog switch circuit

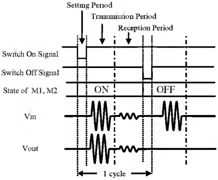
The driving sequence of the ultrasound imaging system consists of the switch setting period, the ultrasound transmission period, and the reception period. Considering this sequence, we developed the new analog switch circuit and its control time sequence shown in Figure 2. In this circuit, M1 and M2 are the main switch devices whose source electrodes are connected with each other. We selected a thin gate oxide process of 12V to reduce the channel resistance and the MOSFET cell size. The gate and the source electrodes of the main switches are connected to the gate control circuit, which has bi-directional blocking capability. In the setting period, before the ultrasound signal is applied to the input terminal, the main switches are turned ON and OFF by the control circuit as follows:

Turn on main switch: turn on M5 and M4, the gate source voltage of M3 is discharged by M4, and M3 turns off. The gate source voltages of M1 and M2 are charged up to the control supply voltage by the discharge current flow through the transducer and parasitic capacitance.

Turn off main switch: turn on M6 and M3, so that the gate



(a) Schematic of the switch circuit



(b) Time sequence

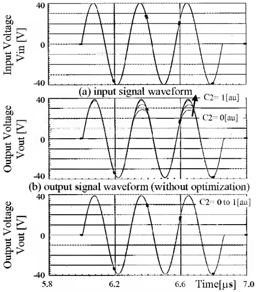
Fig. 2. Schematic of the switch circuit and control time sequence diagram

source voltages of M1 and M2 are discharged. M5 or M6 are turned on only during setting period. The gate electrode of the main switch is kept floating by the bi-directional blocking circuit and the gate voltage level is maintained by the latch circuit during the transmission period and reception period when the ultrasound signal is applied to the analog switch. Since the voltage between gate and source does not exceed the control power supply voltage, this analog switch circuit can handle an input voltage that is higher than the control power supply voltage as well as a negative voltage with in the range of the blocking capability of the main switches and the bi-directional blocking circuit.

The loss of the gate control circuit is very low because the control current flows for a very short time and the current stops just after the change of state (from ON to OFF, or from OFF to ON) is completed.

B. Design of the analog switch circuit for ultrasound application

We designed the proposed switch circuit carefully considering the quality of the ultrasound signal wave form, that is, to prevent signal distortion. As mentioned, many analog switches are required in this ultrasound imaging system. Therefore, the input capacitance of the switch circuit must be small to reduce signal attenuation. For this purpose, we improved the accuracy of the parasitic capacitance models of the device, and a device structure with low parasitic



(c) output signal waveform (with optimization)

Fig. 3. Simulation results of output voltage dependency on C2

capacitance was designed. Moreover, M1 and M2 were designed with the most suitable on-resistance to maximize the ratio of output and input signal amplitudes, with the total system simulation including the impedance of the switches, the transducers, the transmission/reception circuit, and the cable that connects the hand probe to the transmission/reception circuit.

It is very important to reduce the change of the gate voltage during the ultrasound transmission period. The voltage between the gate and source of M1 and M2 in the proposed circuit can be changed by the discharged current flows through the parasitic capacitance of MOSFETs, and it may lead to signal distortion and deterioration of off isolation performance. To prevent the change of the gate voltage, the device structure and layout of the circuit were examined, and the capacitance values of C1 and C2 were introduced. Figure 3 shows the simulation result of the transmit operation. In this figure, (a) shows the ±40V 3.5MHz input signal, (b) shows the output signal of original device structure circuit, (c) shows the output signal of the circuit with optimized device structure and layout, and the variation range of C2 the same as in (b) and (c). From Figure 3(b), it can be seen that the signal distortion improved with larger C2. By employing an optimized device structure and layout, the output signal closely follows the input signal even when C2 is small, as shown in the same figure (c).

C. Voltage spike reduction and improvement of the off isolation

In the proposed switch circuit, the spike voltage is generated by the current that flows from the control power supply to the transducers during the switch setting period. In the ON or OFF update operation, the spike voltage is small because the current from the control power supply is very small. However, when the main switch changes from OFF to ON or from ON to OFF, a current flows from the control power

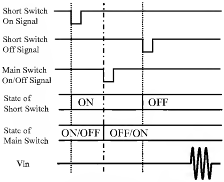


Fig. 4. Control time sequence diagram of short switch

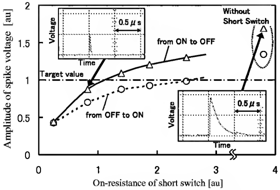


Fig. 5. Dependence of the amplitude of spike voltage with the on-resistance of short switch

supply through M5 and M3 or M6 and M4, and a spike voltage is generated at the Vout terminal with which transducer is connected. The spike voltage leads to an unnecessary ultrasound beam into the subject, and causes a false image. To reduce the spike voltage, additional analog switches are connected between Vin and ground, and between Vout and ground, and these allow the short of these terminals to ground. These additional short switches are turned ON before the setting period of the main switches according to the control time sequence shown in Figure 4. As a result, the spike voltage can be decreased because of the reduced impedance of Vin and Vout to ground. Figure 5 shows the amplitude of the spike voltage as a function of the normalized on-resistance of the short switch. In Figure 5, the on-resistance of the short-circuit switch is normalized by the on-resistance of the main switch, and the amplitude of spike voltage is normalized by the target value. As shown in this figure, the amplitude of the spike voltage is decreased below the target specification by designing the on-resistance of the short switch to be at the same level as the on-resistance of the main switch. In addition, it is expected that the generation of an unnecessary ultrasound beam will be decreased further by using the short switch because the frequency spectrum of the spike voltage rises, and occurs in the dead band of the transducer.

Moreover, the off isolation performance can be improved with this short switch. When the main switch is OFF, the short switch connected with Vout terminal is kept in an ON state during the transmission and the reception period. The short switch of the Vout terminal shorts the transducer, reduces the effective impedance of the transducer and leads to the reduction of the voltage of Vout and an improvement in the off isolation.

80V 32x32ch Multiplexer LSI

A. Construction of the developed LSI

Figure 6 shows the block diagram of the developed LSI. This LSI contains one thousand analog switches in a 32 X 32 array, which is 100 times as many switches as a conventional high voltage analog switch LSI. The 6bit control data is loaded serially via shift data inputs and clocked into a shift register via shift clock. Short switches using the same type of analog switch in a 32 X 32 array are installed in this LSI to reduce voltage spikes and to improve the off isolation.

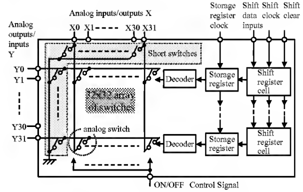


Fig. 6. Block diagram of multiplexer LSI

Figure 7 shows a top view of the developed LSI. This LSI was fabricated with a 0.35μm SOI process for a narrow isolation area, low parasitic capacitance, and high logic operation speed. The SOI process also provides parasitic bipolar action for negative voltage inputs.

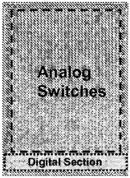
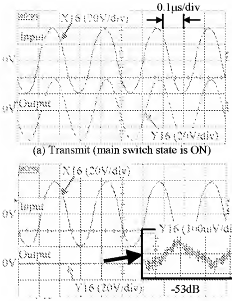


Fig. 7. Top view of multiplexer LSI

B. Experimental results

Figure 8 shows the experimental waveforms of the input and the output signals of the developed LSI. The frequency is 4MHz with an amplitude of 80Vpp. In the ON state, the output signal closely follows the input signal. In the OFF state, the output signal level is lower than 200mV and shows a reasonably good off isolation performance of -53dB. Figure 9 illustrates the experimental results of the off isolation



(a) Transmit (main switch state is ON)

(b) Isolation (main switch state is OFF)

Fig. 8. Input/output ultrasound signal waveforms of the multiplexer LSI

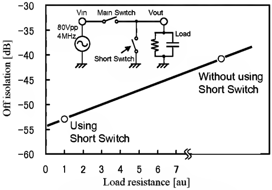


Fig. 9. Experimental results of off isolation with function of load resistance

performance with and without the short switch. The off isolation performance is improved by about 10dB by using the short switch.

Figure 10 shows a prototype probe. This probe includes more than two hundred of our new LSIs, which control eight thousand transducers. The LSIs are chip-on-board (COB) mounted with wire bonding on a printed circuit board (PCB), with about 30 PCBs stacked. The loss of the LSI is about 10 mW/LSI. Figure 11 shows a 3D fetal phantom image obtained using a prototype probe. A finely detailed real-time 3D volume image can be achieved with this probe, and no false images caused by spike voltages appear.

Table 1 summarize the features of the developed LSI.

Conclusion

A new concept for an 80V multiplexer LSI with the world's largest 32 X 32ch cross-point switches for a real-time 3D ultrasound imaging system was presented. We developed a

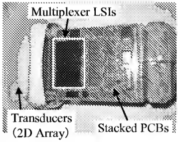


Fig. 10. Prototype probe

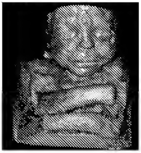


Fig. 11. Fetal phantom 3D reconstruction image

Table. 1. Features of developed LSI

Number of Switches	32 X 32
Analog Signal Range	±40V
Power Dissipation	10mW/LSI
Analog Band Width (-3dB)	15MHz
Off isolation	-53dB
Clock Frequency	33MHz

new gate floating type analog switch circuit with 12V thin gate oxide power MOSFETs and a low-loss gate driving method. An 80V 32 X 32ch multiplexer LSI which can handle ±40V signals at low loss (10mW/LSI) was developed. Moreover, we also adopted a new method for switching noise reduction and off isolation improvement (-53dB), and optimized device structures with low parasitic capacitance for a wider analog signal bandwidth (15MHz). A detailed real-time 3D volume image can be achieved with the developed LSIs.

The results clearly show that the proposed new analog switch concept and developed LSI are very suitable for high voltage, multi-channel, low-loss analog switch applications.

References

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